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(54) **Support for chondrocyte transplantation in cartilage and joint repair**

Trägerstruktur für die Chondrozytentransplantation zur Reparatur von Knorpeln und Gelenken

Support pour la transplantation de chondrocytes pour la réparation de cartilages et des articulations

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Description

[0001] The instant invention concerns the field of chondrocyte transplantation, bone and cartilage grafting, healing, joint repair and the prevention of arthritic pathologies. Methods for the preparation of the graft site, instruments for such preparation and for the autologous transplantation of cells to the prepared graft site are described.

[0002] More than 500,000 arthroplastic procedures and total joint replacements are performed each year in the United States. Approximately the same number of similar procedures are performed in Europe. Included in these numbers are about 90,000 total-knee replacements and around 50,000 procedures to repair defects in the knee per year in Europe. The number of procedures are essentially the same in the U. S. (In: Praemer A., Furner S., Rice, D.P., Musculoskeletal conditions in the United States, American Academy of Orthopaedic Surgeons, Park Ridge, I11., 1992, 125). A method for regeneration-treatment of cartilage would be most useful, and could be performed at an earlier stage of joint damage, thus reducing the number of patients needing artificial joint replacement surgery. With such preventative methods of treatment, the number of patients developing osteoarthritis would also decrease.

[0003] Techniques used for resurfacing the cartilage structure in joints have mainly attempted to induce the repair of cartilage using subchondral drilling, abrasion and other methods whereby there is excision of diseased cartilage and subchondral bone, leaving vascularized cancellous bone exposed (Insall, J., Clin. Orthop. 1974,101,61; Ficat R.P. et al, Clin Orthop. 1979, 144, 74; Johnson L.L., In: Operative Arthroscopy, McGinty, J.B., Ed., Raven Press, New York, 1991, 341).

[0004] Coon and Cahn (Science 1966, 153, 1116) described a technique for the cultivation of cartilage synthesizing cells from chick embryo somites. Later Cahn and Lasher (PNAS USA 1967, 58, 1131) used the system for analysis of the involvement of DNA synthesis as a prerequisite for cartilage differentiation. Chondrocytes respond to both EFG and FGF by growth (Gospodarowicz and Mescher, J. Cell Physiology 1977, 93, 117), but ultimately lose their differentiated function (Benya et al., Cell 1978, 15, 1313). Methods for growing chondrocytes were described and are principally being used with minor adjustments by Brittberg, M. et al. (New Engl. J. Med. 1994, 331, 889). Cells grown using these methods were used as autologous transplants into knee joints of patients. Additionally, Kolettas et al. (J. Cell Science 1995, 108, 1991) examined the expression of cartilage-specific molecules such as collagens and proteoglycans under prolonged cell culturing. They found that despite morphological changes during culturing in monolayer cultures (Aulthouse, A. et al., In Vitro Cell Dev. Biol., 1989,25,659; Archer, C. et al., J. Cell Sci. 1990,97,361; Hänselmann, H. et al., J. Cell Sci. 1994,107,17; Bonaventure, J. et al., Exp. Cell Res. 1994,212,97), when compared to suspension cultures grown over agarose gels, alginate beads or as spinner cultures (retaining a round cell morphology) tested by various scientists did not change the chondrocyte - expressed markers such as types II and IX collagens and the large aggregating proteoglycans, aggrecan, versican and link protein did not change (Kolettas, E. et al., J. Cell Science 1995,108,1991).

[0005] The articular chondrocytes are specialized mesenchymal derived cells found exclusively in cartilage. Cartilage is an avascular tissue whose physical properties depend on the extracellular matrix produced by the chondrocytes. During endochondral ossification chondrocytes undergo a maturation leading to cellular hypertrophy, characterized by the onset of expression of type X collagen (Upholt, W.B. and Olsen, R.R., In: Cartilage Molecular Aspects (Hall, B & Newman, S, Eds.) CRC Boca Raton 1991, 43; Reichenberger, E. et al., Dev. Biol. 1991, 148, 562; Kirsch, T. et al., Differentiation, 1992, 52, 89; Stephens, M. et al., J. Cell Sci. 1993, 103, 1111).

[0006] Excessive degradation of type II collagen in the outer layers or articular surfaces of joints is also caused by osteoarthritis. The collagen network is accordingly weakened and subsequently develops fibrillation whereby matrix substances such as proteoglycans are lost and eventually displaced entirely. Such fibrillation of weakened osteoarthritic cartilage can reach down to the calcified cartilage and into the subchondral bone (Kempson, G.E. et al., Biochim. Biophys. Acta 1976, 428, 741; Roth, V. and Mow, V.C., J. Bone Joint Surgery, 1980, 62A, 1102; Woo, S.L.-Y. et al., in Handbook of Bioengineering (R. Skalak and S. Chien eds.), McGraw-Hill, New York, 1987, pp. 4.1-4.44).

[0007] Descriptions of the basic development, histological and microscopic anatomy of bone, cartilage and other such connective tissues can be found for example in Wheater; Burkitt and Daniels, Functional Histology, 2nd Edition, (Churchill Livingstone, London, 1987, Chp. 4). Descriptions of the basic histological anatomy of defects in bone, cartilage and other connective tissue can be found for example in Wheater, Burkitt, Stevens and Lowe, Basic Histopathology, (Churchill Livingstone, London, 1985, Chp. 21).

[0008] Despite the advances in cultivating chondrocytes, and manipulating bone and cartilage, there has not been great success with the attempts to transplant cartilage or chondrocytes for the repair of damaged articulating surfaces. The teachings of the instant invention provide for effective and efficient means of promoting the transplantation of cartilage and/or chondrocytes into a defect in an articulating joint or other cartilage covered bone surface, whereby cartilage is regenerated to fix the defect. The instant invention also provides for surgical instruments which are designed prepare the graft site so as to facilitate the efficient integration of grafted material to the graft site.

WO 96/24310, US-17-4 846 835 and WO 95/30742 de-

scribe cartilage repair structures.

[0009] The object of the invention is defined in the claims.

[0010] The instant invention provides a cartilage repair structure usable in a method for the effective treatment of articulating joint surface cartilage by the transplantation of chondrocytes in a suitable matrix, to a surface to be treated, with a hemostatic barrier and a cell-free covering-patch comprising; first placing a hemostatic barrier proximal to the surface to be treated, placing chondrocytes in a suitable matrix upon the surface to be treated distal to the hemostatic barrier, covering the surface to be treated with a cell-free covering-patch. A hemostatic barrier, as will be further described below, is a barrier which inhibits or prevents the penetration of vascularizing cells and tissue into the grafted material. In particular, the instant method provides for a hemostatic barrier that is a resorbable, semi-permeable material which inhibits or prohibits vascular infiltration through the barrier. In one embodiment the hemostatic barrier contains collagen. Cell-free, is used herein as in the art, and means a material that is substantially free from intact cells which are capable of further cell division, promulgation or biological activity. In a preferred embodiment, a cell-free material is free from all intact nucleated cells. In one embodiment a cell-free covering patch which contains a semi-permeable collagen matrix can be used. In one preferred embodiment the porous surface of the cell-free covering-patch is directed towards the implant material.

[0011] The instant invention further provides a cartilage repair structure for the autologous transplantation of collagen or chondrocytes to a graft site, wherein the graft site has first been prepared by surgical manipulation to better accept the grafted material. In one embodiment, the graft site is to be sculpted such that the walls of the graft site are contoured in an undulating pattern such that the grafted material, when placed within the graft site and expanded to contact the graft site wall, there will be resistance against removal or expulsion of the entire graft from the graft site. Surgical instruments designed to sculpt the graft site can be used.

[0012] The present invention will be better understood by examining the following figures which illustrate certain properties of the instant invention wherein:

Figure 1A is a drawing showing a typical articulating end of a bone. Typically, the bone material is covered on the articulating surface with a cartilaginous. Figure 1B shows an example of where a defect or injury to the cartilaginous cap occurs (gap in cartilage), and such a defect can be treated directly, enlarged slightly, or sculpted to accept the grafted material by surgical procedures prior to treatment.

Figure 1C shows how the hemostatic barrier (numbered 1) is placed within the defect in the cartilage cap to inhibit or prevent vascularization into regenerating cartilage, from the underlying bone. The chondrocytes to be implanted into the defect cavity are then layered on top of the hemostatic barrier.

Figure 2 is a drawing showing the treated defect (gap in cartilage) in the cartilaginous cap covered by a cell-free semi-permeable material (numbered 2) which is used to form a cap/patch or bandage over the defect site. This cap is fixed in place, either sutured to the edge of the cavity into healthy cartilage, or otherwise attached. This cap is covering the defective area of the joint into which the cultured chondrocytes/cartilage transplant has been placed, or will be placed under the partially attached cap.

Figure 3A is a diagram illustrating the differential response to compression and shearing forces by harder and softer cartilage with subsequent zone of demarcation.

Figure 3B illustrates the graft site, after the defect has been sculpted to have undulating walls.

Figure 3C illustrates the sculpted graft site with the hemostatic barrier (1), transplanted material (3), and cell-free covering-patch (2) in place within the articular surface cartilage (4).

Figure 4A illustrates one embodiment of the surgical device of the instant invention showing cutting teeth (5) and protruding placement pin (6). The cross-section illustrations to the right show two possible configurations of the cutting blades.

Figure 4B illustrates a second embodiment of the surgical device of the instant invention.

Figure 5 is a diagram illustrating the modified differential response to compression and shearing forces by harder cartilage and softer cartilage after sculpting the graft site.

Figure 6A is an MRI image of a pig knee showing cartilage defect in left (medial) condyle.

Figure 6B is an MRI image of the same pig knee three months after treatment.

[0013] This invention concerns the use of certain products that inhibit the formation of vascular tissue, for instance such as capillary loops projecting into the cartilage being established, during the process of autologous transplantation of chondrocytes into defects in the cartilage. The formation of vascular tissue from the underlying bone will tend to project into the new cartilage to be formed leading to appearance of cells other than the mesenchymal specialized chondrocytes desired.

[0014] The contaminating cells introduced by the vascularization may give rise to encroachment and overgrowth into the cartilage to be formed by the implanted chondrocytes. One of the types of commercial products which can be used in this invention is Surgicel® (Ethicon Ltd., UK) which is absorbable after a period of 7 - 14 days. The use of this material is contrary to the normal use of a hemostatic device, such as Surgicel® as it is described in the package insert from Ethicon Ltd.

[0015] Surprisingly, we have found that in a situation where you wish to inhibit re-vascularization into carti-

lage, a hemostatic material will act like a gel-like artificial coagulate. If red blood cells should be present within the full-thickness defect of articular cartilage that is capped by such a hemostatic barrier, these blood cells will be chemically changed to hematin, and thus rendered unable to induce vascular growth. Thus a hemostatic product used as a re-vascularization inhibitory barrier with or without fibrin adhesives, such as for example the Surgicel®, is effective for the instant invention. According to the invention a cell-free component is to be used that is used as a patch covering the defective area of the joint into which the cultured chondrocytes/cartilage are being transplanted, using autologous chondrocytes for the transplantation. The use of suitable allogenic chondrocytes or xenogenic chondrocytes for the repair of a cartilage defect is also contemplated.

[0016] Thus the cartilage repair structure according to the instant invention can be used for effective repair or treatment of cartilage defects in articular joint bone surfaces which comprises administering an agent or device to block vascular invasion into the cartilage site to be repaired, and also providing for a cell-free barrier which will isolate the repair site and keep transplanted cells in place. A hemostatic barrier component for insertion into the site to be repaired is provided such that there is effective inhibition of vascularization into the site to be repaired; and once the chondrocytes to be transplanted are placed into the site to be repaired, a cell-free semipermeable barrier is capped over the repair site such that the transplanted chondrocytes are held in place, but are still able to gain access to nutrients.

[0017] Certain aspects of the invention have been exemplified using an *in vitro* system to study the behavior of the chondrocytes when in contact with a certain product or a combination of certain products that inhibit the formation of vascular tissue. This *in vitro* testing predicts the ability of certain tested materials to inhibit vascularization, as will occur *in vivo* where capillary loops project into the cartilage being established during the process of autologous transplantation of chondrocytes into defects in the cartilage.

[0018] Suitable hemostatic products will be characterized by having the ability to inhibit the growth, or invasion of vascular tissue, osteocytes, fibroblasts etc. into the developing cartilage. A suitable hemostatic material will achieve the goal of the method of the instant invention in that vascular and cellular invasion into developing cartilage should be prevented in order to optimize the formation of cartilage and achieve repair of the full-thickness of any defects in the articular cartilage. Ideally, the hemostatic barrier will be stable for an extended period of time sufficient to allow for full cartilage repair, and then be able to be resorbed or otherwise broken down over time. One material identified as suitable is called Surgicel® W1912 (an absorbable hemostat containing oxidized regenerated sterile cellulose; Lot GG3DH, Ethicon Ltd. UK). Another example of a suitable material is BioGide® (a commercially available type I collagen matrix pad; Geistlich Söhne, Switzerland).

[0019] Suitable organic glue material can be found commercially, such as for example Tisseel® or Tissucol® (fibrin based adhesive; Immuno AG, Austria), Adhesive Protein (Cat. #A-2707, Sigma Chemical, USA), and Dow Corning Medical Adhesive B (Cat. #895-3, Dow Corning, USA).

[0020] The surgical instruments can be manufactured from metal and/or plastic suitable for making single-use disposable, or multi-use reusable surgical instruments. The cutting instrument may contain cutting teeth that are fully circular or flat, or anything in between. As cartilage is a relatively soft material it may be advantageous to manufacture hardened plastic cutting edges which will be able to sculpt cartilage without being able to damage bone. Such cutting instruments can be manufactured to incorporate openings for administration of fluid, suction removal of cutting debris and fluid, and fiber optic threads for illumination and visualization of the defect site.

[0021] Certain aspects of the instant invention may be better understood as illustrated by the following examples, which are meant by way of illustration and not limitation.

Example 1

[0022] In order for the Surgicel® to be used according to the invention for preventing development of blood vessels into autologous implanted cartilage or chondrocytes, Surgicel® was first treated with a fixative, such as glutaric aldehyde. Briefly, Surgicel® was treated with 0.6% glutaric aldehyde for 1 minute, followed by several washings to eliminate glutaric aldehyde residues that may otherwise be toxic to tissue. Alternatively, the Surgicel® was treated with the fibrin adhesive called Tisseel® prior to treatment with glutaric aldehyde as described in Example 2. It was found that the Surgicel® fixated for instance with a fixative such as glutaric aldehyde, washed with sterile physiological saline (0.9%) and stored in refrigerator, does not dissolve for 1 to 2 months. Generally, Surgical is resorbed in a period between 7 and 14 days. This time would be too short, because a longer time is needed in preventing the development of blood vessels or vascularization as such from the bone structure into the implanted cartilage before the implanted chondrocytes have grown into a solid cartilage layer getting its nutrition requirements from the neighboring cartilage. In other words sufficient inhibition of the vascularization is needed for a longer time such as for instance one month. Therefore, the product should not be absorbed significantly prior to that time. On the other hand resorption is needed eventually. Hence, the organic material used as an inhibiting barrier shall have these capabilities, and it has been found that the Surgicel® treated in this manner provides that function.

Example 2

[0023] The Surgicel® was also coated with an organic glue, in this example the glue used was Tisseel® but others can also be used. This product, together with the Surgicel® produces a useable barrier for the particular purpose of the invention. Any other hemostat or vascular inhibiting barrier could be used. The Tisseel® was mixed as described below. The Surgicel® was then coated with Tisseel® by spraying the Surgicel® material on both sides until soaked. The Tisseel® (fibrin glue) was then allowed to solidify at room temperature. Immediately prior to completed solidification, the coated Surgicel® was then placed in 0.6% glutaric aldehyde for 1 minute and then washed with sterile physiological (0.9%) saline. The pH was then adjusted by PBS and/ or with NaOH until pH was stable at 7.2 to 7.4. Afterwards the thus treated Surgicel® was then washed in tissue culture medium such as minimum essential medium/F12 12 with 15 mM Hepes buffer.

[0024] As mentioned in this example we have used Tisseel® as the fibrin adhesive to coat the Surgicel®. Furthermore the fibrin adhesive or glue may also be applied directly on the bottom of the lesion towards the bone, on which the Surgicel® is glued. The *in vitro* system used, in lieu of *in vivo* testing, consisted of a NUNCLON™ Delta 6-well sterile disposable plate for cell research work (NUNC, InterMed, Roskilde, Denmark). Each well measures approximately 4 cm in diameter.

[0025] In the invention the fibrin adhesive can be any adhesive which together with the fibrin component will produce a glue that can be tolerated in humans (Ihara, N, et al., Bums Incl. Therm. Inj., 1984, 10, 396). The invention also anticipates any other glue component that can be used in lieu of the fibrin adhesive. In this invention we used Tisseel® or Tissucol® (Immuno AG, Vienna, Austria). The Tisseel® kit consists of the following components:

Tisseel® a lyophilized, virus-inactivated Sealer, containing clottable protein, thereof: fibrinogen, Plasma fibronectin (CIG) and Factor XIII, and Plasminogen.
Aprotinin Solution (bovine)
Thrombin 4 (bovine)
Thrombin 500 (bovine)
Calcium Chloride solution

[0026] The Tisseel® kit contains a DUPLOJECT® Application System. The fibrin adhesive or the two-component sealant using Tisseel® Kit is combined in the following manner according to the Immuno AG product insert sheet:

Example 3

[0027] Chondrocytes were grown in minimal essential culture medium containing HAM F12 and 15 mM Hepes buffer and 5 to 7.5% autologous serum in a CO_2 incubator at 37°C and handled in a Class 100 laboratory at Verigen Europe A/S, Symbion Science Park, Copenhagen, Denmark. Other compositions of culture medium may be used for culturing the chondrocytes. The cells were trypsinized using trypsin EDTA for 5 to 10 minutes and counted using Trypan Blue viability staining in a Bürker-Türk chamber. The cell count was adjusted to 7.5×10^5 cells per ml. One NUNCLON™ plate was uncovered in the Class 100 laboratory.

[0028] The Surgicel® hemostatic barrier was cut to a suitable size fitting into the bottom of the well in the NUNCLON™ tissue culture tray. In this case a circle, of a size of approximately 4 cm (but could be of any possible size) and placed under aseptic conditions on the bottom in well in a NUNCLON™ Delta 6-well sterile disposable plate for cell research work (NUNC, InterMed, Roskilde, Denmark). The hemostatic barrier to be placed on the bottom of the well was pre-treated as described in Example 1. This treatment delays the absorption of the Surgicel significantly. This hemostatic barrier was then washed several times in distilled water and subsequently several times until non-reacted glutaraldehyde was washed out. A small amount of the cell culture medium containing serum was applied to be absorbed into the hemostatic barrier and at the same time keeping the hemostatic barrier wet at the bottom of the well.

[0029] Approximately 10^6 cells in 1 ml culture medium were placed directly on top of the hemostatic barrier, dispersed over the surface of the hemostatic barrier pretreated with 0.4% glutaraldehyde as described above. The plate was then incubated in a CO_2 incubator at 37°C for 60 minutes. An amount of 2 to 5 ml of tissue culture medium containing 5 to 7.5% serum was carefully added to the well containing the cells avoiding splashing the cells by holding the pipette tip tangential to the side of the well when expelling the medium. It appeared that the pH of the medium was too low (pH ~6.8). The pH was then adjusted to 7.4 to 7.5. The next day some chondrocytes had started to grow on the hemostatic barrier, arranged in clusters. Some of the cells had died due to the low pH exposure prior to the adjustment of the pH. The plate was incubated for 3 to 7 days with medium change at day 3.

[0030] At the end of the incubation period the medium was decanted and cold refrigerated 2.5% glutaraldehyde containing 0.1M sodium salt ofdimethylarsinic acid, (also called sodium cacodylate, pH is adjusted with HCl to 7.4), was added as fixative for preparation of the cell and supporter (hemostatic barrier) for later preparation for electron microscopy.

Example 4

[0031] Chondrocytes were grown in minimal essential culture medium containing HAM F12 and 15 mM Hepes buffer and 5 to 7.5% autologous serum in a CO_2 incubator at 37°C and handled in a Class 100 laboratory at

Verigen Europe A/S, Symbion Science Park, Copenhagen, Denmark. Other compositions of culture medium may be used for culturing the chondrocytes. The cells were trypsinized using trypsin EDTA for 5 to 10 minutes and counted using Trypan Blue viability staining in a Bürker-Türk chamber. The cell count was adjusted to 7.5×10^5 cells per ml. One NUNCLON™ plate was uncovered in the Class 100 laboratory.

[0032] The Surgicel® (for use as the hemostatic barrier) was treated with 0.6% glutaric aldehyde for one minute as described in Example 1, and washed with 0.9% sterile sodium chloride solution or, preferably, with a buffer such as a PBS buffer or the culture medium such as MEM/F12, because pH after the glutaric aldehyde treatment is 6.8 and should preferably be 7.0 to 7.5. The Tisseel® was applied on both side of the Surgicel® using the DUPLOJECT® system, thus coating both sides of the Surgicel®, the patch intended to be used, with fibrin adhesive. The glue is left to dry under aseptic condition for at least 3 to 5 minutes. The "coated" hemostatic barrier was placed on the bottom of the well in a NUNCLON™ Delta 6-well sterile disposable plate for cell research work. A small amount of tissue culture medium containing serum was applied to be absorbed into the hemostatic barrier. Approximately 10^6 cells in 1 ml tissue culture medium containing serum was placed directly on top of the Hemostat, dispersed over the surface of the hemostatic barrier. The plate was then incubated in a CO_2 incubator at 37°C for 60 minutes. An amount of 2 to 5 ml of tissue culture medium containing 5 to 7.5 % serum was carefully added to the well containing the cells avoiding splashing the cells by holding the pipette tip tangential to the side of the well when expelling the medium. After 3 to 6 days, microscopic examination showed that the cells were adhering to and growing into the Surgicel® in a satisfactory way suggesting that Surgicel® did not show toxicity to the chondrocytes and that the chondrocytes grew in a satisfactory manner into the Surgicel®.

[0033] The plate was incubated for 3 to 7 days with medium change at day 3. At the end of the incubation period the medium was decanted and cold refrigerated 2.5% glutaraldehyde containing 0.1M sodium salt of dimethylarsinic acid, also called sodium cacodylate, pH is adjusted with HCl to 7.4, was added as fixative for preparation of the cell and supporter (hemostatic barrier) for later preparation for electron microscopy.

Example 5

[0034] Chondrocytes were grown in minimal essential culture medium containing HAM F12 and 15 mM Hepes buffer and 5 to 7.5% autologous serum in a CO_2 incubator at 37°C and handled in a Class 100 laboratory at Verigen Europe A/S, Symbion Science Park, Copenhagen, Denmark. The cells were trypsinized using trypsin EDTA for 5 to 10 minutes and counted using Trypan Blue viability staining in a Bürker-Türk chamber. The cell count was adjusted to 7.5×10^5 to 2×10^6 cells per ml. One NUNCLON™ plate was uncovered in the Class 100 laboratory.

[0035] It has been found that the Bio-Gide® can be used as a resorbable bilayer membrane which will be used as the patch or bandage covering the defective area of the joint into which the cultured chondrocytes are being transplanted as well as the hemostatic barrier. The Bio-Gide® is a pure collagen membrane obtained by standardized, controlled manufacturing processes (by E.D. Geistlich Sohne AG, CH-61 10 Wolhusen). The collagen is extracted from veterinary certified pigs and is carefully purified to avoid antigenic reactions, and sterilized in double blisters by γ-irradiation. The bilayer membrane has a porous surface and a dense surface. The membrane is made of collagen type I and type III without further cross-linking or chemical treatment. The collagen is resorbed within 24 weeks. The membrane retains its structural integrity even when wet and it can be fixed by sutures or nails. The membrane may also be "glued" using fibrin adhesive such as Tisseel® to the neighboring cartilage or tissue either instead of sutures or together with sutures.

[0036] The Bio-Gide® was un-covered in a class 100 laboratory and placed under aseptic conditions on the bottom of the wells in a NUNCLON™ Delta 6-well sterile disposable plate for cell research work, either with the porous surface of the bilayer membrane facing up or with the dense surface facing up. Approximately 10^6 cells in 1 ml tissue culture medium containing serum was placed directly on top of the Bio-Gide®, dispersed either over the porous or the dense surface of the Bio-Gide®. The plate was then incubated in a CO_2 incubator at 37°C for 60 minutes. An amount of 2 to 5 ml of tissue culture medium containing 5 to 7.5 % serum was carefully added to the well containing the cells avoiding splashing the cells by holding the pipette tip tangential to the side of the well when expelling the medium.

[0037] On day 2 after the chondrocytes were placed in the well containing the Bio-Gide® the cells were examined in a Nikon Inverted microscope. It was noticed that some chondrocytes had adhered to the edge of the Bio-Gide. It was of course not possible to be able to look through the Bio-Gide® itself using this microscope.

[0038] The plate was incubated for 3 to 7 days with medium change at day 3. At the end of the incubation period the medium was decanted and cold refrigerated 2.5% glutaraldehyde containing 0.1M sodium salt of dimethylarsinic acid, also called sodium cacodylate, pH is adjusted with HCl to 7.4, was added as fixative for preparation of the cell and the Bio-Gide® supporter with the cells either cultured on the porous surface or the dense surface. The Bio-Gide® patches were then sent for electron microscopy at Department of Pathology, Herlev Hospital, Denmark.

[0039] The electron microscopy showed that the chondrocytes cultured on the dense surface of the Bio-Gide® did not grow into the collagen structure of the Bio-

Gide®, whereas the cells cultured on the porous surface did indeed grow into the collagen structure and furthermore, showed presence of proteoglycans and no signs of fibroblast structures. This result shows that when the collagen patch, as for instance a Bio-Gide® patch is sewn as a patch covering a cartilage defect the porous surface shall be facing down towards the defect in which the cultured chondrocytes are to be injected. They will then be able to penetrate the collagen and produce a smooth cartilage surface in line with the intact surface, and in this area a smooth layer of proteoglycans will be built up. Whereas, if the dense surface of the collagen is facing down into the defect the chondrocytes to be implanted will not integrate with the collagen, and the cells will not produce the same smooth surface as described above.

Example 6

[0040] Chondrocytes were grown in minimal essential culture medium containing HAM F12 and 15 mM Hepes buffer and 5 to 7.5% autologous serum in a CO_2 incubator at 37°C and handled in a Class 100 laboratory at Verigen Europe A/S, Symbion Science Park, Copenhagen, Denmark. The cells were trypsinized using trypsin EDTA for 5 to 10 minutes and counted using Trypan Blue viability staining in a Bürker-Türk chamber. The cell count was adjusted to 7.5×10^5 to 2×10^6 cells per ml. One NUNCLON™ plate was uncovered in the Class 100 laboratory.

[0041] The Bio-Gide® used as a resorbable bilayer membrane may also be used together with an organic glue such as Tisseel® with additional, significantly higher content of Aprotinin than normally found in Tisseel® as described in the product insert. By increasing the content of Aprotinin to about 25,000 KIU/ml, the resorption of the material will be delayed by weeks instead of the normal span of days.

[0042] To test this feature *in vitro*, the Tisseel® is applied to the bottom of the well of the NUNCLON™ plate, and allowed to solidify incompletely. A collagen patch such as a Bio-Gide® is then applied over the Tisseel® and glued to the bottom of the well. This combination of Bio-Gide® and Tisseel® is designed to be a hemostatic barrier that will inhibit or prevent development or infiltration of blood vessels into the chondrocyte transplantation area. This hybrid collagen patch can now be used for both as a hemostatic barrier at the bottom of the lesion (most proximal to the surface to be repaired) but also as a support for cartilage formation because the distal surface can be the porous side of the collagen patch and thus encourage infiltration of chondrocytes and cartilage matrix. Thus this hybrid collagen patch can also be used to cover the top of the implant with the collagen porous surface directed down towards the implanted chondrocytes and the barrier forming the top. The hybrid collagen patch, with elevated Aprotinin component may also be used without any organic glue such as Tisseel® and placed within the defect directly, adhering by natural forces. Thus the collagen patch can be used both as the hemostatic barrier, and the cell-free covering of the repair/transplant site, with the porous surfaces of the patches oriented towards the transplanted chondrocytes/cartilage. Another variant would use a collagen patch which consists of type II collagen (ie. from Geistlich Sohne AG, CH-6110 Wolhusen).

[0043] Thus the instant invention provides for a hybrid collagen patch where said patch is a collagen matrix with elevated levels of aprotinin component, preferably about 25,000 KIU/ml, in association with an organic matrix glue, where the collagen component is similar to the Bio-Gide® resorbable bilayer material or Type II collagen, and the organic glue is similar to the Tisseel® material. In another embodiment, the hybrid collagen patch does not use any organic glue to adhere to the site of the repair.

Example 7

[0044] Because of the weakened structure of osteoarthritic cartilage, adherence of cultured autologous chondrocytes transplanted to a graft site in defective cartilage may be inhibited, thus creating a marginal zone (zone of demarcation) between the newly implanted cartilage/chondrocytes and the surrounding established cartilage. This marginal zone will be most pronounced if the graft site is prepared for the graft by creating straight, smooth walls cut in a linear fashion. The shearing and compression forces across such a marginal zone (as illustrated in Figure 3A) will exert great force to dislodge the graft when the graft site is cut in a linear fashion. This marginal zone, and differential movement of materials along this zone will inhibit confluent healing between the grafted material and the surrounding material. This marginal zone shearing is exacerbated when the hardness of the abutting material is different. In many cases the graft material is softer than the surrounding material, however, in some instances of osteoarthritis disease, the surrounding cartilage may in fact be softer than the implanted chondrocytes/cartilage.

[0045] Therefore, in order to solve this problem, surgical instruments can be used to sculpt the walls of the graft site such that the walls are non-linear, and thus provide for undulated surfaces which will reduce marginal zone shearing and provide anchorage for grafted material. It is also possible to shape the graft site such that the diameter of the site proximal to the bone surface is of a greater dimension then the opening distal to the bone and at the surface of the cartilage to be repaired such that there is a "reverse funnel" effect. A narrowed opening at the surface will aid in reducing marginal zone shearing and the expulsion of graft material from the graft site. Sculpting of the walls of the graft site in an fashion similar to a threaded opening for receiving a bolt or screw (as illustrated in Figure 3B) is preferred, thus providing mechanical resistance to the compression

and or ejection of the grafted material from the graft site which can be described as "male" and "female" threading.

[0046] The surgical instruments can be manufactured from metal and/or plastic suitable for making single-use disposable, or multi-use reusable surgical instruments. As cartilage is a relatively soft material it may be advantageous to manufacture hardened plastic cutting edges which will be able to sculpt cartilage without being able to damage bone. Such cutting instruments can be manufactured to incorporate openings for administration of fluid, suction removal of cutting debris and fluid, and fiber optic threads for illumination and visualization of the defect site. In certain instruments the base of the instrument may have protruding point or pin-like structure which will assist in guiding and placing the instrument in the graft site. Of course such a pin would be designed to minimized damage to the underlying bone.

[0047] While the cutting surface of the instrument may be single toothed, or multi-toothed, or describe a screw-like pattern such as that in a metal tap used to generate threaded holes in metal parts, the characteristic required of the cutting instrument is that the resulting sculpted sides of the graft site is undulated, and non-linear. For example, in certain cases, the cutting edge of the instrument can be shaped similar to that shown in Figure 4A, or as in Figure 4B. The cutting edge maybe flat, or circular in that it wraps around the diameter of the cutting instrument. Many other shapes can be designed to create an interface which provides for mechanical resistance to differential reaction to compression and shearing forces on the transplanted material and the surrounding material.

Example 8

[0048] A four month old mixed Yorkshire breed pig was subjected to general anesthesia and placed on its back. The pig was washed and draped in a surgical suite at Harrington Arthritis Research Center, Phoenix, Arizona. The entire surgical procedure was performed aseptically. The left hind-leg and adjacent abdomen and inguinal area was cleaned with iodine. The knee joint was localized, and the patella localized. A medial incision was performed approximately 3 cm from the posterior part of the patella and the several subcutis, muscle layers and ligaments was cut approximately in order to get access to the medial femoral condyle. Using a circular cutter a lesion was prepared in the white cartilage on the medial part of the medial condyle, leaving a 0.5 to 1 cm margin to the edge of the cartilage covering the posterior-medial part of the condyle (left condyle, Figure 6A). The 0.5 to 1 cm defect was placed in a caudal weight bearing part of the medial condyle. The entire surgical procedure was done without tourniquet on the left femur. The different layers and skin was sutured appropriately.

[0049] On day 3 the animal was again brought to the surgical suite and positioned as above on the operating table and given general anesthesia. The left hind leg, abdomen and inguinal region was ionized as described above. Sutures were cut and the area opened. It was noticed that a moderate hematoma was present in the knee joint. The blood clot was removed and the defect inspected. There was a blood clot in the defect which was removed. A sterile surgical instrument designed with a male thread cutting edge, with a size corresponding to, or slightly bigger than the circumference of the lesion was carefully screwed down into the defect. A BioGide® pad was cut to a size equal to the bottom of the defect. The first glue used, called Adhesive Protein (A-2707, Sigma Chemical, USA) was applied on the dense side of the trimmed hemostatic barrier pad, and the pad was placed dense side down into the bottom of the lesion, using it as a barrier as described above. It was found that this glue did not seem to dry very fast. The slight bleeding from the bottom of the defect stopped immediately. A second BioGide® was cut somewhat bigger in circumference than the lesion and was placed with dense side up (thus the porous side down towards the graft) as described above.

[0050] This non-cellular covering-pad was then sutured over the cavity, leaving one edge open, where the chondrocyte to be explanted could be injected into the graft site. The surrounding part of the edge of the pad was covered with the second glue, Dow Coming Medical Adhesive B (Cat. #895-3, Dow Coming, USA). This second glue dried much faster and more efficiently than the first glue. It was found that during this particular procedure, the first glue had not dried sufficiently to hold the hemostatic barrier in place when suturing of the cap was attempted. The main barrier formed on the proximal surface of the graft site was by the glue itself.

[0051] Using a 1 ml syringe and a 16 gauge needle, the chondrocyte cell suspension (about 0.6 ml) was drawn up into the barrel of the syringe. A 23 gauge short needle was switched for the 16 gauge needle, and the cell suspension was injected under the sutured covering-patch into the graft site (about 10 x 10^6 cells). The open edge of the cap was then glued prior to removal of the needle, and the needle carefully withdrawn. No leakage of cells was seen. The wound was sutured and as above, no tourniquet was used, no bleeding was observed. The final skin layers were sutured. No protrusion of the skin occurred after suturing, which indicates that there was no hematoma. Postoperative recovery was uneventful.

[0052] As expected, the grafted chondrocytes produced cartilage matrix sufficient to repair the defect made in the articular cartilage surface of the knee joint of the test pig. Figure 6A is an MRI image of a pig knee showing the cartilage defect created in the knee (left condyle, the medial condyle), and Figure 6B is an MRI image of the same pig knee three months after treatment showing repair of the defect.

Example 9

[0053] In a surgical setting a kit can provide sterile components suitable for easy use in the surgical environment, and will provide a suitable hemostatic barrier, suitable covering patch, and if needed organic glue. A kit may also provide sterile, cell-free matrix material suitable for supporting autologous chondrocytes that are to be implanted into an articular joint surface defect. In one case, a kit contains a surgicel® hemostatic barrier and a Bio-Gide® covering patch with suitable coating of Tisseel® organic glue, where the Surgicel® and Bio-Gide® have been treated according to the teachings of the invention to increase the time till resorption. In instances where Tisseel® is pre-coated, the Tisseel® is supplemented with additional aprotinin to increase time till resorption.

[0054] It is preferred that the hemostatic barrier and covering-patch are both a semi-permeable collagen matrix which is treated to extend the time till resorption of the material. It is also possible to provide Tisseel® glue in enhanced form as a separate component to be applied as needed because of the inherent variability and unique circumstances every repair/transplantation procedure will encounter.

[0055] It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention shown in the specific embodiments without departing form the scope of the invention as described.

Claims

1. A cartilage repair structure for repair of a defect in articular cartilage comprising: a cell-free component, said component having a porous surface and a dense surface; and chondrocytes cells adhered to said porous surface of said component.

2. A cartilage repair structure according to claim 1, wherein said component is collagen.

3. A cartilage repair structure according to claim 2, wherein said component is in particular Type I and Type III collagen.

4. A cartilage repair structure according to any of claims 1 to 3, wherein said component is resorbable.

5. A cartilage repair structure according to any of claims 1 to 4, wherein said chondrocyte cells are autologous, allogenic and/or xenogenic.

6. A cartilage repair structure according to any of claims 1 to 5 further comprising biocompatible adhesive adjacent said component.

7. A cartilage repair structure according to any of claims 1 to 6, wherein said component is adapted to be disposed over the articular cartilage defect.

8. A cartilage repair structure according to any of claims 1 to 6, wherein said component is adapted to be disposed in the articular cartilage defect.

Patentansprüche

1. Struktur zur Wiederherstellung von Knorpel zur Reparatur eines Defekts von Gelenkknorpel, umfassend:

   eine zellfreie Komponente, wobei die Komponente eine poröse Oberfläche und eine dichte Oberfläche aufweist; und
   Chondrozytenzellen, die an der porösen Oberfläche der Komponente anhaften.

2. Struktur zur Wiederherstellung von Knorpel gemäß Anspruch 1, wobei die Komponente Collagen ist.

3. Struktur zur Wiederherstellung von Knorpel gemäß Anspruch 2, wobei die Komponente insbesondere Typ I und Typ III Collagen ist.

4. Struktur zur Wiederherstellung von Knorpel gemäß einem der Ansprüche 1 bis 3, wobei die Komponente resorbierbar ist.

5. Struktur zur Wiederherstellung von Knorpel gemäß einem der Ansprüche 1 bis 4, wobei die Chondrozytenzellen autolog, allogen und/oder xenogen sind.

6. Struktur zur Wiederherstellung von Knorpel gemäß einem der Ansprüche 1 bis 5, weiterhin umfassend einen an die Komponente angrenzenden biokompatiblen Klebstoff.

7. Struktur zur Wiederherstellung von Knorpel gemäß einem der Ansprüche 1 bis 6, wobei die Komponente derart ausgebildet ist, um auf den Gelenkknorpeldefekt angeordnet zu werden.

8. Struktur zur Wiederherstellung von Knorpel gemäß einem der Ansprüche 1 bis 6, wobei die Komponente derart ausgebildet ist, um in dem Gelenkknorpeldefekt angeordnet zu werden.

Revendications

1. Structure de réparation de cartilage pour la réparation d'un défaut du cartilage articulaire comprenant : un composant acellulaire, ledit com-

posant ayant une surface poreuse et une surface dense ; et des cellules chondrocytes adhérant à ladite surface poreuse du dit composant.

2. Structure de réparation de cartilage selon la revendication 1 dans laquelle ledit composant est du collagène.

3. Structure de réparation de cartilage selon la revendication 2 dans laquelle ledit composant est en particulier du collagène de type I et de type III.

4. Structure de réparation de cartilage selon l'une quelconque des revendications 1 à 3 dans laquelle ledit composant est résorbable.

5. Structure de réparation de cartilage selon l'une quelconque des revendications 1 à 4 dans laquelle lesdites cellules chondrocytes sont autologues, allogéniques et/ou xénogènes.

6. Structure de réparation de cartilage selon l'une quelconque des revendications 1 à 5 comprenant en outre un adhésif biocompatible adjacent au dit composant.

7. Structure de réparation de cartilage selon l'une quelconque des revendications 1 à 6 dans laquelle ledit composant est adapté pour être placé sur le défaut du cartilage articulaire.

8. Structure de réparation de cartilage selon l'une quelconque des revendications 1 à 6 dans laquelle ledit composant est adapté pour être placé dans le défaut du cartilage articulaire.

FIG. 1A

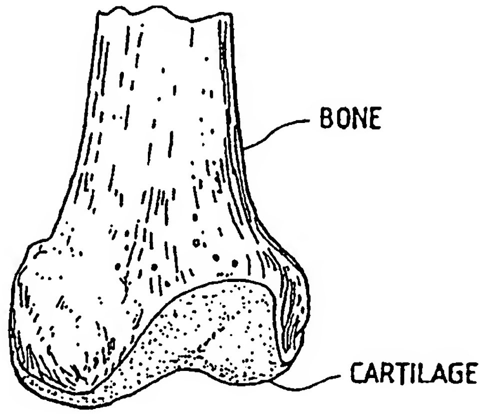

FIG. 1B

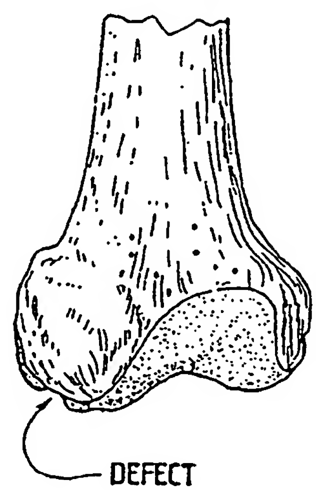

FIG. 1C

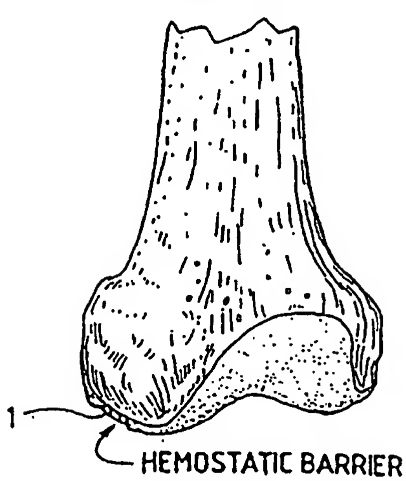

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FIG. 2

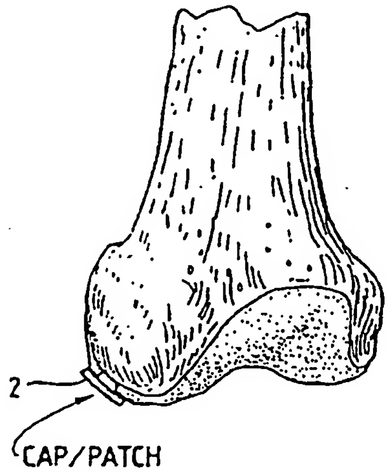


FIG. 3A

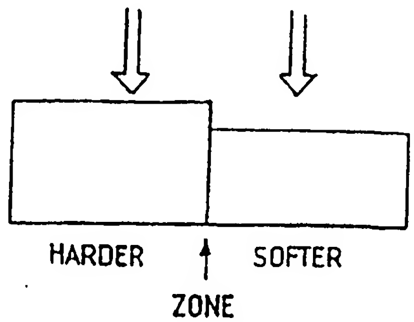


FIG. 3B

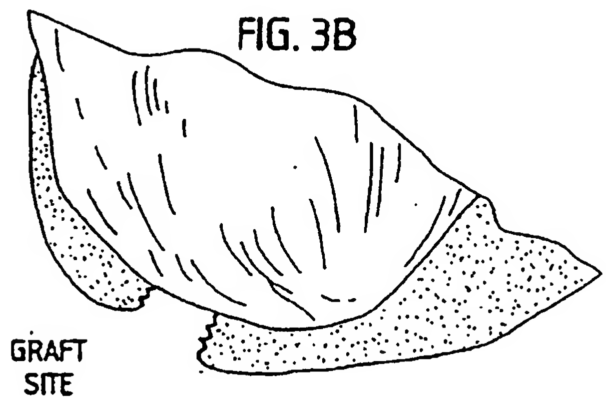


FIG. 3C

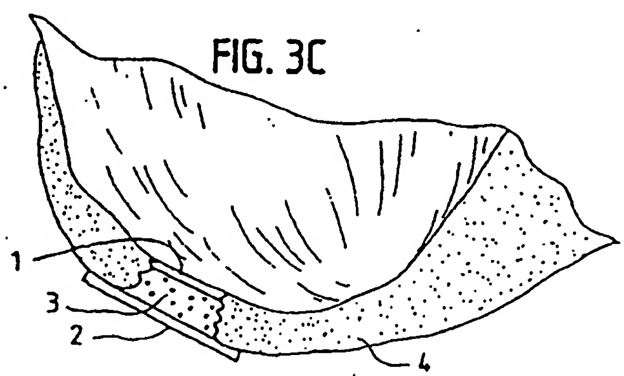


FIG. 4A

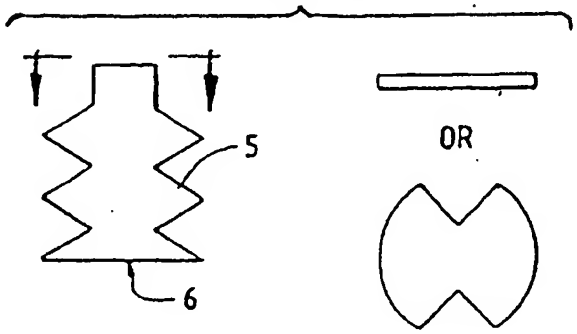


FIG. 4B

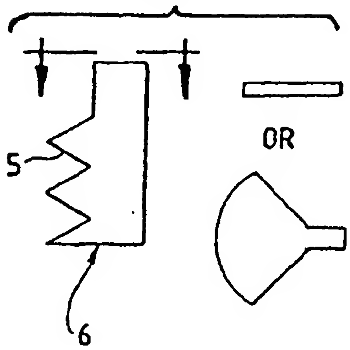
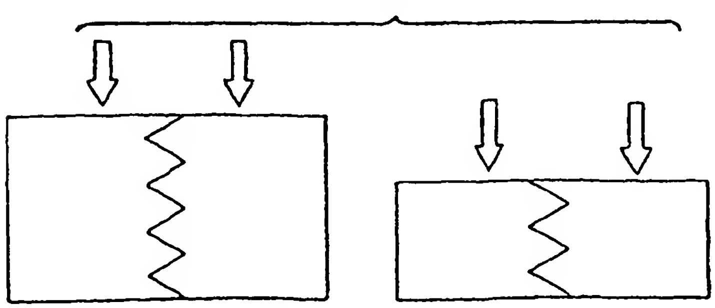


FIG. 5



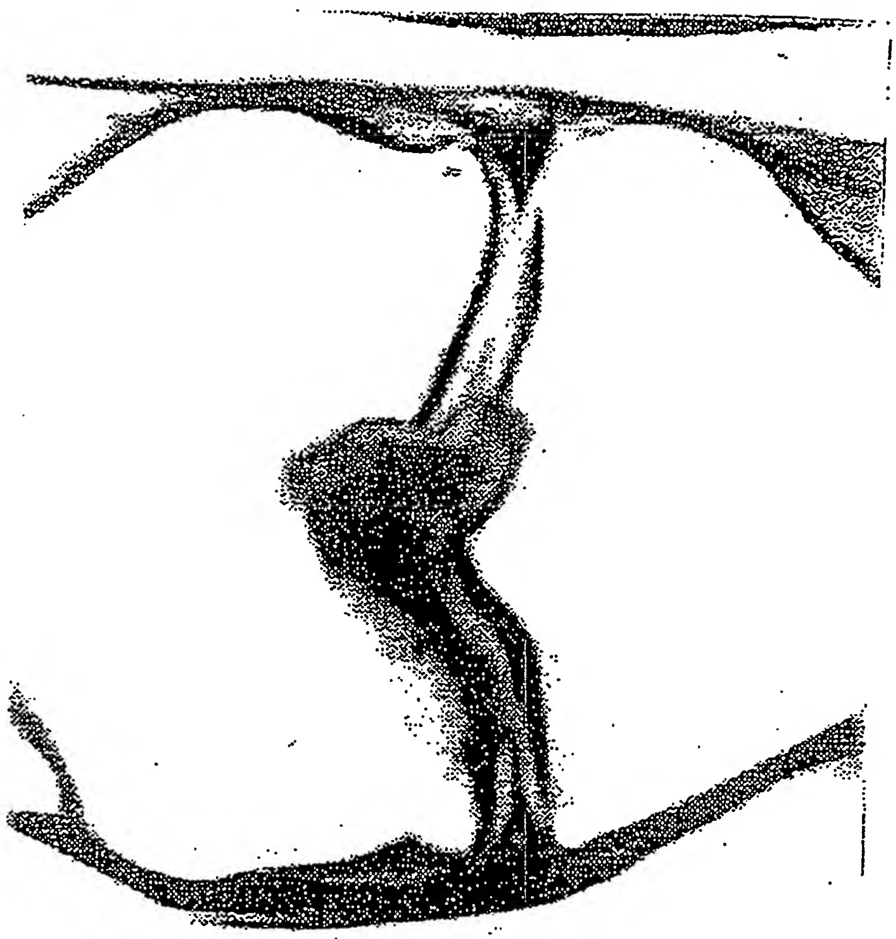


FIG.6A

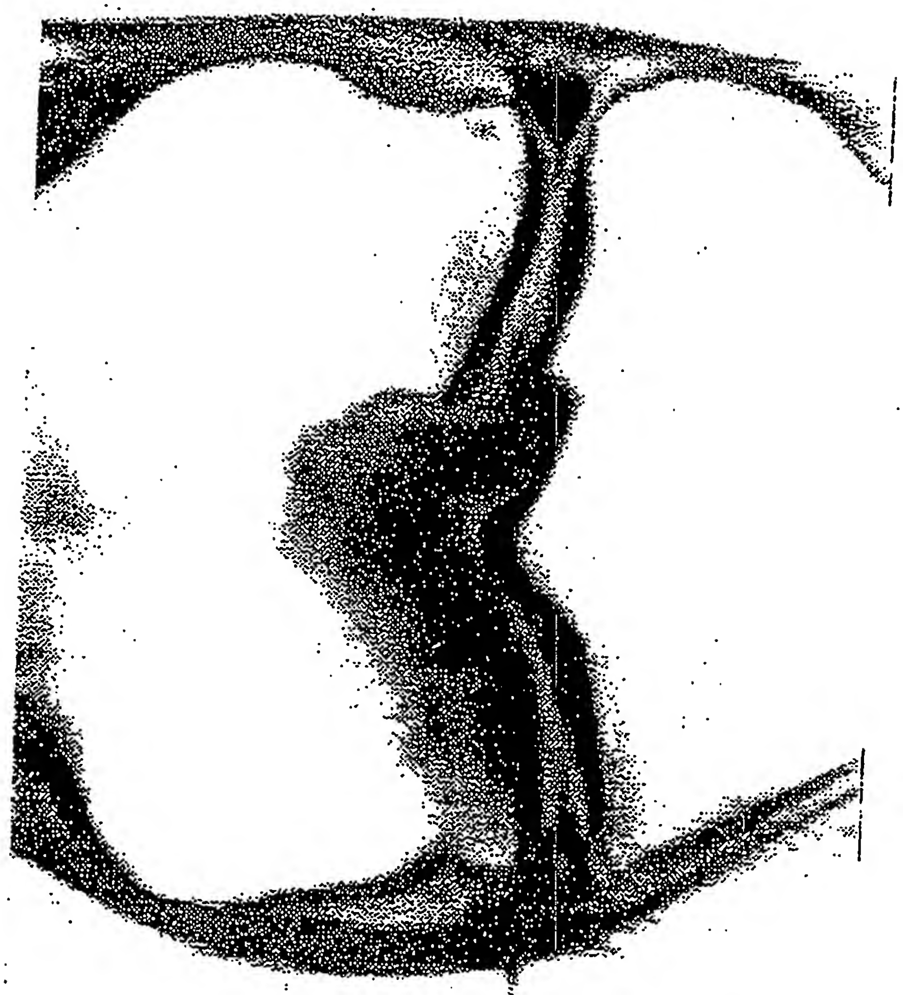


Fig. 6B